

Docket No.: H0610.0362/P362  
(PATENT)

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

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In re Patent Application of:  
Ivar I. Primdahl et al.

Application No.: Not Yet Assigned

Filed: Concurrently Herewith

Art Unit: N/A

For: METHOD OF MEASURING HIGH  
TEMPERATURES AND INSTRUMENT  
THEREFORE  
\_\_\_\_\_

Examiner: Not Yet Assigned

**CLAIM FOR PRIORITY AND SUBMISSION OF DOCUMENTS**

MS Patent Application  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Sir:

Applicant hereby claims priority under 35 U.S.C. 119 based on the following  
prior foreign application filed in the following foreign country on the date indicated:

<u>Country</u>	<u>Application No.</u>	<u>Date</u>
Denmark	PA 2003 00599	April 19, 2003


Application No.: Not Yet Assigned

Docket No.: H0610.0362/P362

In support of this claim, a certified copy of the said original foreign application is filed herewith.

Dated: April 5, 2004

Respectfully submitted,

By 

Stephen A. Soffen

Registration No.: 31,063

DICKSTEIN SHAPIRO MORIN &  
OSHINSKY LLP

2101 L Street NW

Washington, DC 20037-1526

(202) 785-9700

Attorney for Applicant



# Kongeriget Danmark

Patent application No.: PA 2003 00599

Date of filing: 19 April 2003

Applicant:  
(Name and address) Haldor Topsøe A/S  
Nymøllevej 55  
DK-2800 Kgs. Lyngby  
Denmark

Title: Fremgangsmåde til fremstilling af høje temperaturer i kemiske reaktorer og temperatur måleinstrument dertil.

IPC: G 01 K 1/12; G 01 K 7/02.

This is to certify that the attached documents are exact copies of the above mentioned patent application as originally filed.



**Patent- og Varemærkestyrelsen**  
Økonomi- og Erhvervsministeriet

01 March 2004

  
John Nielsen

## BACKGROUND OF THE INVENTION

## Field of the invention

5

The invention relates to measurement of high temperatures in chemical reactors. It specifically is directed to measurement of temperatures in catalytic reactors where endothermic reactions are carried out at high temperatures.

10 In the petrochemical industry autothermal reformers are operating under these conditions.

## Description of related art

15

In autothermal reformers or gasifiers the process gas entering the catalyst bed is typically 1000 - 1500°C, and the process gas contains hydrocarbons, hydrogen, carbon monoxide, water vapour and sometimes nitrogen. Under these severe  
20 conditions the temperature most often is not measured.

A temperature measurement arrangement is disclosed in US patent no. 6,302,578, showing a thermowell installed in a thick reactor wall. This is done in such a way, that there  
25 is a layer of hotface brick between the interior of the reactor and the tip of the thermowell with thermocouple, which thereby is protected against the high temperatures.

In PCT/US91/05432 another high temperature measurement is  
30 described. Here the thermocouple is protected by means of layers of ceramic insulation and a ceramic sheath.

However, these instruments are shielded from the reaction gasses and will not give an immediate indication of temperature changes of the gases. This is especially important for temperature of gasses entering a catalyst bed in autothermal reformers, as this temperature is extremely sensitive to changes in flow ratio between hydrocarbon feed and oxygen source.

## 10 SUMMARY OF THE INVENTION

The invention provides a method for measurement of high temperatures of a process stream by means of a thermocouple arranged in a thermowell, wherein the thermowell is at least partly covered by a layer of a catalytic material being active in at least one endothermic reaction.

It further relates to a temperature measurement wherein the thermowell is installed in a reactor by inserting the thermowell through a hole in reactor wall so that the tip of the thermowell is in contact with the process stream.

It is thereby possible to let the hot gas stream contact the thermowell, as the endothermic reaction in the catalyst keeps the temperature of the metal surface of the thermowell tip considerably lower than the temperature of the gas. In this way, changes in gas temperature can be instantaneously detected.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1 is a cross sectional view of a temperature-measuring  
 5 instrument according to a specific embodiment of the invention.

FIG 2 is a front view of FIG 1.

10 FIG 3 shows a typical installation of the measuring instrument shown in the above Figures.

## DETAILED DESCRIPTION OF THE INVENTION

15

The invention is especially directed to temperature measurement in autothermal reformers where hydrocarbons undergo first a partial oxidation and then a reforming process.

20 The partial oxidation is an exothermic reaction while the reforming process is an endothermic process whereby the first reaction provides heat to the second process.

By the partial oxidation some of the hydrocarbons react to  
 25 form carbon oxide and steam:



The resulting process gas then undergoes a reforming reaction:  
 30



The overall reforming is an endothermic reaction.

A hydrocarbon feed gas and an oxygen containing gas are  
10 mixed at the inlet of the reactor.

The hydrocarbon feed gas typically contains steam, hydrocarbon, hydrogen and carbon oxides and it is fed to the reformer at temperatures between 100 and 900°C. The oxygen  
15 source is pure oxygen, air or any mixture hereof at a temperature between ambient temperature and up to 700°C.

The pressure in the reactor can be 2-8 MPa, most often it is 2.5-5 MPa, and when the feed streams are mixed, the exothermic  
20 oxidation process starts.

Although the content of oxygen corresponds to only partial combustion of the hydrocarbon the temperature rise is extremely high.

25

In the space between inlet of reactor and catalyst bed, the endothermic reforming reaction starts due to the high temperature and ends at 1000-1500°C. At steam/carbon ratios of 1.5 this reaction ends at about 1250°C and at steam/carbon  
30 ratio of 0.6 at about 1335°C.

The reaction continues in the catalyst bed to almost complete conversion of hydrocarbons and the temperature of the reacted, reformed process gas is typically 900-1100°C.

5 By the method of the invention the temperature of the gas entering the catalyst bed is measured by a thermocouple in a thermowell provided with a layer of catalyst being active in catalysing endothermic reactions. Although it is a relatively thin layer and the reaction may not be entirely complete,  
10 the endothermic reaction will cool the surface of the thermowell considerably.

At the same time the signal from the temperature instrument of the invention is stronger than one from a measurement of  
15 prior art. This is explained by the following.

In case the oxygen containing feed stream to an autothermal reformer increases during normal operation, an increased amount of hydrocarbon is oxidised. This has both the consequence that the temperatures increase and that the remaining  
20 amount of hydrocarbon to be reformed decreases.

At this higher start temperature for the endothermic reaction the conversion is increased in the space without catalyst. Thereby, much less endothermic reaction takes place in  
25 the catalyst.

This means, that the total temperature drop in the reactor decreases, the temperature drop in the empty space increases  
30 and the temperature drop across the catalyst decreases -even more than the total decrease of temperature drop.



In this change of operation situation, a conventional temperature instrument installed just upstream of the catalyst detects a corresponding temperature increase, which is lower than the temperature increase at the inlet of the reactor.

5 Contrary to this, a temperature instrument of the invention detects a temperature increase corresponding to catalyst outlet temperature, and this temperature increase is even higher than the temperature increase at the inlet of the reactor.

10

The same difference in temperature change also applies, when the relative oxygen amount decreases.

The above illustrates, that the invention has the advantages  
15 of measuring the temperature with a much lower metal surface temperature, of creating a stronger signal and of measuring the gas it self inlet the catalyst bed. Measuring the catalyst outlet gas or measuring behind a shield would create a considerable time delay.

20

The temperature of the partially combusted process gas is very sensitive to the ratio between flow of hydrocarbon and flow of oxygen source.

25 Consequently, it is highly desired to detect a change in this temperature as quickly as possible. This is possible with the temperature measurement of the invention.

One preferred embodiment of the invention is shown on FIG 1.  
30 The measuring junction 1 of the thermocouple 2 is installed in the tip of thermowell 3, and the tip of the thermowell is covered by a catalytic layer 4. This is in contact with pro-

cess gas in the reactor chamber 5. The inner surface of the reactor wall is covered by tiles 10, which are able to withstand the high reaction temperatures. The outer surface of the reactor wall is the reactor shell 11, which is designed for the full operation pressure. Between 10 and 11 three layers of insulating refractory material 12, 13 and 14 are installed.

The tip of the thermowell is somewhat withdrawn from the inner surface of the reactor wall to protect it against radiation from the flame at top of the reactor. The measuring junction of the thermocouple is 20 - 50 mm from the inner surface of the wall.

As the thermal expansion of the tiles and refractory differs from the one of the metal pressure shell, to which the thermowell is connected, the height of the hole in the tiles and outer refractory layer will be bigger than the width of the hole. The dimensions are adapted to the thermal expansions, which in industrial autothermal reformers typically are a height of 80 - 100mm and a width of 35 - 40mm. This is further illustrated on FIG 2.

On the thermowell the thickness of the catalyst layer 4 is from 0.2 to 0.5mm. In another embodiment the thermowell tip is inserted into a catalyst tablet and then the "catalyst layer" is 0.5 - 5mm, most often 0.5 - 2mm.

20 - 200 mm of the end of the thermowell can be covered by the catalytic material; most often 40-80mm is covered.

The catalyst 4 can be any catalyst active in reforming reaction. Especially the catalysts with noble metals are very suitable.

5 FIG 3 shows where a thermowell of the invention can be installed in an autothermal reformer. The hydrocarbon feed 1 is mixed with the oxygen containing feed 2 and the partial combustion takes place in burner 3. The process gas temperature is measured by thermocouple 4, before entering catalyst  
10 bed 5 where it is completely reformed to product gas 6.

In the industry the invention is useful in gasifiers, such as autothermal reformers producing synthesis gas in ammonia plants, hydrogen plants, methanol plants and  
15  $H_2$  / CO gas plants. In all these reactors it is very important to thoroughly supervise their performance and especially temperatures in order to obtain a stable and safe operation.

20

#### Example

In a test pilot plant having an adiabatic reactor two experiments at autothermal reforming conditions were conducted.  
25

In both experiments the pressure was 28 kg/cm<sup>2</sup> g (2.8 MPa). The hydrocarbon feed was 97.4 Nm<sup>3</sup>/h natural gas with 2 Nm<sup>3</sup>/h  
30 hydrogen at 562°C. Steam/carbon ratio was 0.38 (on molar basis). The oxygen was fed at 219°C.

Two thermocouples, TI-1 and TI-2, were installed, measuring the gas entering the catalyst bed.

TI-3 measured the gas exit the catalyst bed.

5 Following results were obtained

Measured data	1 <sup>st</sup> experiment	2 <sup>nd</sup> experiment
O <sub>2</sub> / nat. gas, by volume	0.519	0.576
TI-1, °C	1163	1201
TI-2, °C	1184	1221
TI-3, °C	991	1068

Calculated data		
T, inlet, average	1174	1211
$\Delta T$ , inlet-exit	183	143
Increase of T, inlet, average from 1 <sup>st</sup> to 2 <sup>nd</sup> experiment	37	
Increase of T, outlet from 1 <sup>st</sup> to 2 <sup>nd</sup> experiment	77	

5

This demonstrates that when the oxygen content increases, the reaction and the temperature drop decreases in the catalyst bed. Also, the increase from experiment 1 to 2 of catalyst inlet temperature is less than the increase of catalyst outlet temperature. From this it appears that a catalyst coated thermowell installed thermocouple gives a stronger signal and with a lower metal surface temperature.

10

## CLAIMS

1. A method for measurement of high temperatures of a process stream by means of a thermocouple arranged in a thermowell, wherein the thermowell is at least partly covered by a layer of a catalytic material being active in at least one endothermic reaction.  
5
2. Method according to claim 1, wherein tip of the thermowell is covered by the catalytic material with a layer thickness of 0.2 - 5 mm, preferably 0.5 - 2.0 mm.  
10
3. Method according to claim 1, wherein the thermowell is installed in a reactor by inserting the thermowell through a hole penetrating reactor wall so that the tip of the thermowell is in contact with the process stream.  
15
4. Method according to claim 3, wherein the tip of the thermowell is 20 - 50 mm behind inner surface of the reactor wall.  
20
5. Method according to claim 1, wherein the temperature is measured in a process stream undergoing a steam reforming reaction in a catalytic bed.  
25
6. Method according to claim 5, wherein the temperature is measured upstream of the catalyst bed.
7. Method according to claim 5, wherein the steam reforming reaction is carried out in an autothermal reformer.  
30

8. Method according to claim 1, wherein the catalytic material is active in catalysing steam reforming reactions.

9. Method according to anyone of the preceding claims,  
5 wherein the measured process stream has a temperature of  
1000 - 1500°C

10. A temperature measurement instrument comprising a thermocouple inserted in a thermowell being at least partly covered by a layer of a catalytic material being active in at  
10 least one endothermic reaction.

## ABSTRACT

5 The invention provides a method for measurement of high temperatures of a process stream by means of a thermocouple arranged in a thermowell, wherein the thermowell is at least partly covered by a layer of a catalytic material being active in at least one endothermic reaction.

10 The thermowell is installed in a reactor by inserting the thermowell through a hole penetrating the reactor wall so that the tip of the thermowell is in contact with the process stream.

15 The invention is typically used where the reaction is a reforming reaction and the reactor is an autothermal reformer fed with a hydrocarbon stream and an oxygen containing stream.



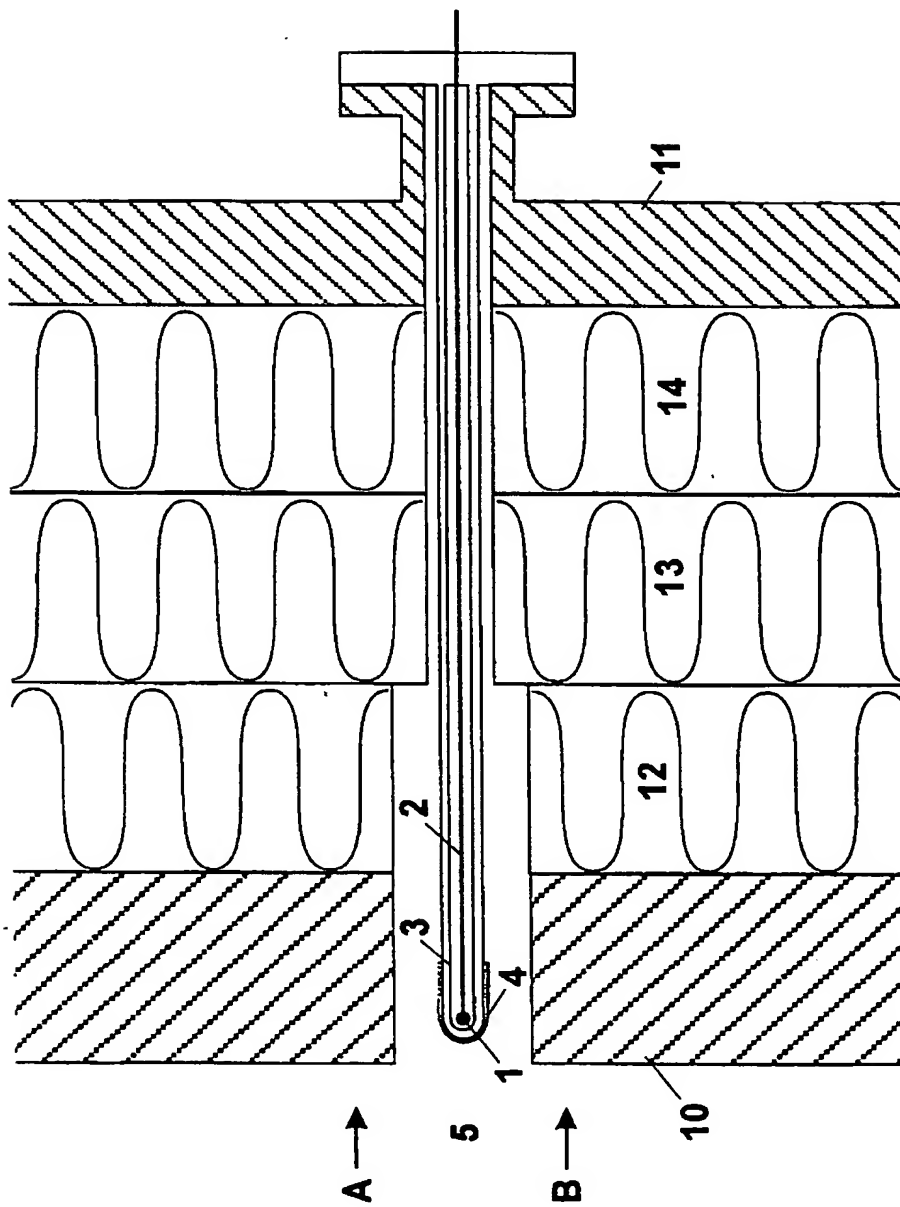
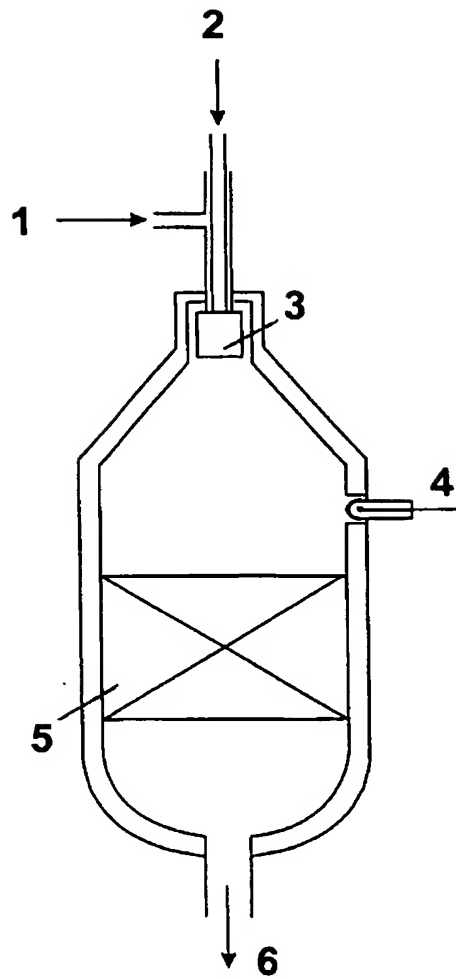


FIG 2

FIG 1

Modtaget  
19 APR. 2003  
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**FIG 3**